



PROPERTIES OF ULTRA LOW FREQUENCY UPSTREAM WAVES AT VENUS AND SATURN: A COMPARISON

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ABSTRACT

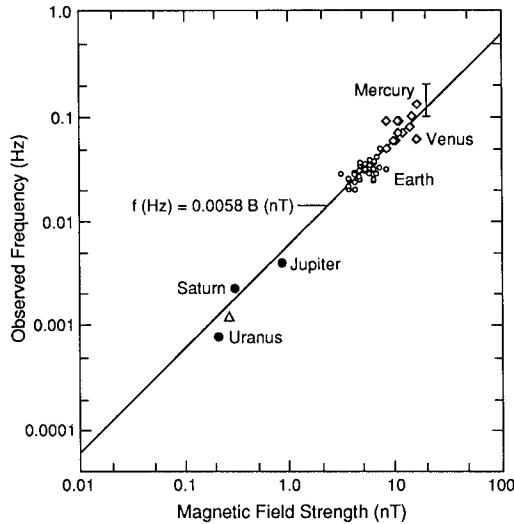
The upstream regions of all planets, except Pluto, have been investigated, using in situ spacecraft measurements and a variety of analysis techniques. The detailed studies at Earth indicate that these waves are generated locally in the magnetically connected solar wind by the interaction with ions backstreaming from the shock. However, since the properties of the solar wind vary with heliocentric distance and since properties of planetary shocks depend on plasma beta, IMF spiral angle and Mach number, the amount of heating, acceleration efficiencies, etc. significantly change with heliocentric distance. In turn the waves seen at each planet propagate not in the same but different (physical) propagation modes. In this paper we compare the ULF wave observations at an outer and an inner planet. We use the results of the linear wave mode identification method of /1/ based on magnetic polarization and magnetic compression ratio, quantities easily derivable with sufficient accuracy at each planet. We use the full electromagnetic dispersion relation for comparison with theoretical predictions.

INTRODUCTION

It is important to study upstream phenomena in planetary foreshocks because the conditions under which they occur differ at each of the planets and some of these conditions cannot be duplicated at Earth. Differences in the low frequency wave phenomena occur for several reasons. *Firstly*, solar wind parameters vary with different rates as a function of heliocentric distance. As a consequence, various plasma ratios, such as plasma beta β (ratio of thermal to magnetic pressure), T_e/T_p , (ratio of electron to proton temperature), ω_p/Ω_p (ratio of proton plasma to proton cyclotron frequency) and ω_e/Ω_e (ratio of electron plasma to electron cyclotron frequency) that modify the dispersion relation and the wave characteristics, vary significantly from planet to planet. Also the variation of the strength (M_{ms}) of the planetary shocks with heliocentric distance /2/, and particularly the n_u/n_d and T_{pu}/T_{pd} (ratios of upstream to downstream plasma densities and proton temperatures, respectively) significantly change the effectiveness of proton reflection and heating processes and modify the properties of the unstable particle populations either reflected /3-6/ or heated at the shock /7/. Also the varying shock structure and strength may indirectly affect the Fermi process /8/ as well as may modify properties of particle populations leaking from the hot magnetosheath or magnetosphere back into the solar wind /9/.

Secondly, the change in the shape and size of the planetary obstacle expressed in terms of the local solar wind proton gyroradius and/or proton inertial length results in a change of the connection time of the IMF to the shock expressed in local proton gyroperiods. For example: at Venus the solar wind typically requires 4-15 t_p (local proton gyroperiods) to flow the distance from shock nose to the terminator while at Saturn the solar wind requires about 6000 - 10000 local t_p to flow this distance. At Venus the typical magnetosonic Mach number varies from 7 to 10 and the foreshock region is typically very small. In contrast at Saturn the solar wind Mach number is generally high between $M_{ms} \sim 20$ to 40 and the large magnetosphere of Saturn ensures a long connection time and large foreshock region.

Despite those differences, the frequencies of the upstream waves observed at all the planets studied to date were found by /10/ to be ordered with the interplanetary magnetic field and resonate with the same particle population, namely the cold reflected ion beam /10/. This ordering discovered by Hoppe and Russell /10/ enabled the prediction of the existence of the upstream waves at particular frequencies at



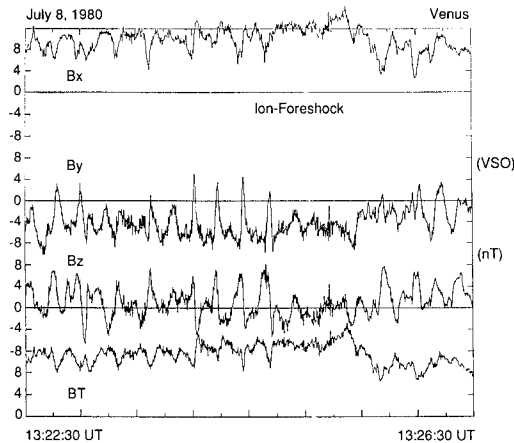
1. Dependence between observed frequency and magnetic field strength for low frequency upstream waves observed in foreshocks of different planets. This figure is taken from Hoppe and Russell [1982].

Saturn, Uranus and Neptune. In Figure 1 the observed frequency versus magnitude of interplanetary magnetic field (f versus B) is shown.

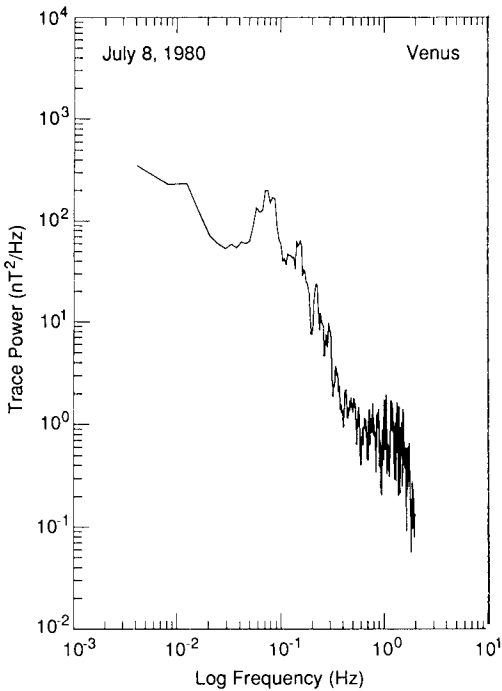
In this paper we show that difference in the plasma environments upstream of the planetary shock of Venus and Saturn result in observable differences in the properties of the low frequency upstream waves at these two planets implying different physical propagation modes. We show that in contrast to Venus not one but two different propagation modes have been identified at Saturn. The existence at Saturn of 2 modes could not be predicted by f versus B dependence derived basically from the observations made in the inner planets [10]. Using the full electromagnetic dispersion relation we show that two different wave modes are simultaneously observed at Saturn that are likely to be generated by two distinct plasma populations.

CHARACTERISTICS OF LOW FREQUENCY ($\omega < \Omega_p$) UPSTREAM WAVES IN THE VENUS FORESHOCK

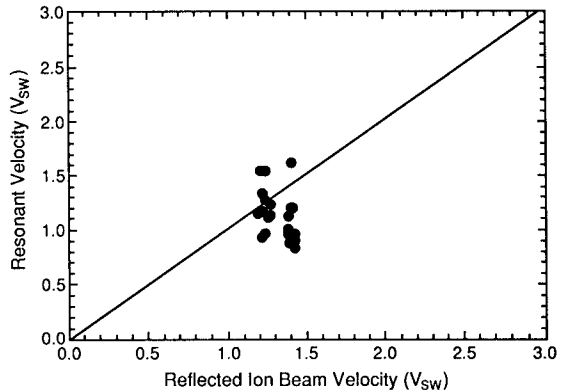
Typical ULF waves in the Venus upstream region observed on June 8, 1980 between 1322 and 1326 UT are shown in Figure 2. The (magnetically) non-compressional and linear character ($\langle \delta B/B_0 \rangle$ less than



2. Time series of components B_x, B_y, B_z and total magnetic field strength BT at Venus from 13:22:30 UT to 13:26:30 UT on July 8, 1980, expressed in the coordinate system VSO similar to GSE. The large amplitude ultra low frequency upstream waves are clearly seen.



3. Trace of the power spectral matrix as a function of spacecraft frame frequency of low frequency upstream waves at Venus on June 5, 1983, 06:37 UT - 06:45 UT. A single spectral peak is clearly distinguished.

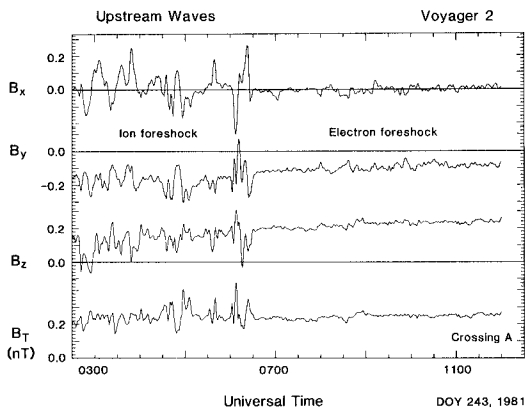


4. The resonant velocity of the cold proton beam calculated from the anomalous resonant condition versus reflected ion beam velocity calculated for planar shock model using Sonnerup [1969] reflection mechanism.

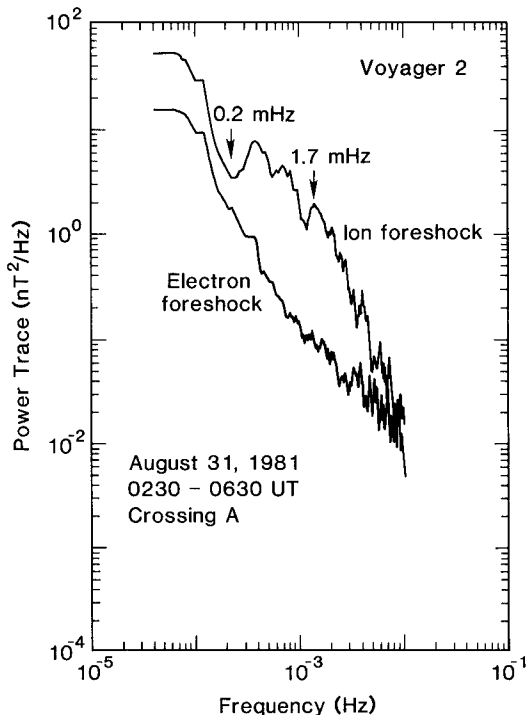
0.1) of these waves is clearly seen. The trace of the power spectral matrix of these waves shown in Figure 3 indicates that these waves are narrow banded, $\Delta f < .04$ Hz, and peak at 0.08 Hz with an amplitude of ~ 1.2 nT. The results of the analysis of the waves from Figure 2 using minimum variance method /11/ indicate that these waves are left-hand elliptically polarized in spacecraft frame (magnetic polarization $P_{B,k}$, of -0.92) propagating upstream at about 12° to the background magnetic field and at 17° to the solar wind flow. The results of the calculation of the resonant velocities of the cold reflected proton beam versus the beam velocity in the shock frame calculated using reflection model /12/ is shown in Figure 4. It is clearly seen these waves are likely in anomalous resonance with the proton beam reflected from the shock having a velocity in the shock frame of $1 \pm 0.25 V_{sw}$ consistent with earlier findings of /10/.

CHARACTERISTICS OF THE LOW FREQUENCY ($\omega < \Omega_p$) UPSTREAM WAVES IN THE SATURN FORESHOCK

In the study of the region upstream of the Saturn bow shock we have used Voyager 2 magnetic field data recorded on August 31, 1981 with low time resolution (48 Sec per vector) data returned by the Goddard magnetometer /13/ during the Voyager 2 outbound passes. See Figure 5. The important features seen in Figure 6 are the spectral peaks at frequencies of 0.35 mHz and 1.7- 2 mHz in the s/c frame. Wave analysis indicates that the 0.35 mHz waves ($\theta_{B,k} = 40-70^\circ$) are RH elliptically polarized with a maximum variance direction pointing in most cases outside of the $\mathbf{k}-\mathbf{B}_0$ plane. The real part of the magnetic polarization is estimated as the signed square root of the ratio between intermediate and maximum eigenvalue of the co-variance matrix obtained by the minimum variance method /11/ ranges typically from 0.2 to 0.7 consistent with earlier analyses /14/. In contrast, the 1.7- 2 mHz waves are left-hand elliptically polarized in the spacecraft frame with a propagation angle of $30^\circ-50^\circ$ to \mathbf{B}_0 . The polarization ranges from -0.7 to -0.9 in the Saturn upstream region. Similar waves have been reported upstream of the bow shock /15/, during the Voyager 1 encounter /15/ and during Voyager 2 encounter /16/.



5. Time series of components B_x, B_y, B_z and total magnetic field strength B_T at Saturn recorded by Voyager 2. The large amplitude ultra low frequency upstream waves are clearly seen in the ion foreshock of Saturn.



6. Trace of the power spectral matrix as a function of spacecraft frame frequency of low frequency upstream waves at Saturn on August 31, 1981, 02:30 UT - 06:30 UT. Within wide range power enhancements observed in the ion foreshock two separated peaks at 0.35 mHz and 1.7 mHz can be clearly distinguished.

SATURN-VENUS: COMPARISON OF WAVE MODES

An analysis of the upstream wave modes at Venus has been performed /1/. This analysis uses a semiempirical identification procedure based on the comparison between measured and calculated from linear Vlasov theory the magnetic polarization and magnetic compression ratio. It indicates that the only mode consistent with the data (Figure 1 and 2) is the normal mode of the fast magnetosonic wave (FMS) both with and without the reflected cold proton beam.

A similar analysis of the upstream wave modes at Saturn /17/ was performed using the same identification procedure based on the comparison of magnetic polarization derived from the data and calculated from linear Vlasov theory. The magnetic polarization indicates that for an isotropic plasma with hot energetic beams, whose properties are consistent with the particle observations at Saturn, there are two distinct modes. The high frequency 1.7 mHz wave grows and propagates in the fast magnetosonic mode (FMS) as at Venus but the low frequency 0.35 mHz wave grows and propagates in the "Alfvénic" beam mode /17/.

CONCLUSION

At Venus only one upstream wave mode, the fast magnetosonic (FMS) wave, has been observed and identified. This mode is consistent with generation by cold reflected ions. At Saturn we observe simultaneously two upstream wave modes, one associated with a cold reflected proton beam and one (Alfvénic beam mode) associated with a hot and energetic proton beam, most probably "leakage" originating from the hot magnetosheath. The lack of the hot component from the Venus sheath is possibly due to the small size of the Venus magnetosheath and the relative weakness of the bow shock of Venus.

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